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Multifunctionality of pastoralism: linking global and local strategies through shared visions and methods

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Proceeding of the Workshop

Multifunctionality of pastoralism:

linking global and local strategies through shared visions and methods

Scientific editors

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The biological bases of environmental values of grassland/rangelands

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INTRODUCTION

The livestock sector's relationship with climate change is complex and raises a number of questions. The sector is a major contributor to agricultural greenhouse gas emissions (GHG), but is itself subject to climate change, and must therefore adapt to ensure its survival. Moreover, livestock production contributes to a significant and increasing extent to food systems and to agricultural systems in developing countries (manure, transportation, savings, income). The place of animals must therefore be reconsidered in designing climate-smart farming systems. However, the focus nowadays is on producing more, and improving the productivity of systems. It is nevertheless recognized that this must be done more sustainably, taking climate change into account (in both developing and developed countries) in terms of adaptation and mitigation (Vigne et al., 2016).

The animal production sector's global emissions amount to 7.1 Gt CO_2 equivalent (CO_2-eq), or 14.5 % of anthropogenic emissions (Gerber et al. 2013), mainly in the form of methane (CH4), nitrous oxide (N2O) and CO_2. This estimate is derived from a life cycle assessment approach and includes emissions from ruminant enteric fermentation, manure and feed production, livestock-induced land use change, and from post-farm energy use. Other study estimates lie in the range of 5.6–7.5 Gt CO_2-eq, with the differences deriving from the scope of their analysis (for example, the IPCC, which reports on direct agricultural emissions for the sector). Cattle are the main contributor to the sector's emissions with about 5.0 gigatonnes CO_2-eq (62 %) and grazing systems are responsible for 1.32 Gt CO_2 -eq/yr or 20% of all emissions (Garnett and al., 2017).

These undeniable livestock emissions are gradually being factored into agricultural development policies in developed countries, while in developing countries they are often seen as a lower priority than the fight against hunger, malnutrition, poverty and economic development. On the other hand, grazing land has a very high GHG mitigation potential (4 % of anthropogenic emissions) by sequestering and storing CO_2 in the soil (Lal 2004). Agricultural soil management is therefore essential for controlling carbon flows in the fight against climate change (90 % of the emission reduction potential of the agricultural sector, according to Gerber et al. 2013).

In this article, we focus on the GHG mitigation options provided by potential carbon sequestration in the soil of pastures of the diverse range of grazing systems worldwide. These systems are specific to ruminants and characterized by the fact that more than 90 percent of dry matter fed to ("grassfed") animals comes from natural grasslands (rangelands), semi-natural grasslands and improved grasslands or pastures. And less than 10% of the total value of production comes from non-livestock farming activities (Garnett et al., 2017).

WHAT IS SOIL CARBON IN GRAZING LIVESTOCK SYSTEM?

The sequestration process

Sequestration is the process of removing carbon from the atmosphere, where it is present in the form of CO_2, and drawing it down into the terrestrial pool, via plants growing on the land. Through photosynthesis (which takes place during daytime due to solar energy) some of the CO_2 is converted into a food source, glucose, and then into other compounds to build the biomass of the plants (accompanied by a production of oxygen). During the night plants breathe (in order to survive this period without light), by using oxygen and carbohydrates. During this respiration process, some CO_2 is released back into the atmosphere.

The carbon accumulated during plant growth is found in above-ground biomass (stem, leaves, flowers, seeds), and some in its root structure. When plants die and decay, part of this carbon is emitted back to the atmosphere as CO_2 (mineralization). Another part may be converted into more stable carbon compounds (soil organic matter. Soil organic matter (SOM) comprises a range of organic molecules ranging from small, easily degraded substances such as sugars exuded by plant roots, through to large, complex organic compounds which resist decomposition and can remain in the soils for decades or centuries. This might occur if biomass is buried or otherwise drawn down deep into soils where it is not disturbed, and in the case of roots which are already below ground.

The SOM may increase, or be re-released within a matter of weeks or months. It does not necessarily become converted into a more stable form and thus in the long term the soil carbon content may not in fact increase. The presence of favourable soil and climatic conditions, in conjunction with land use and management, is critical to the formation of soil carbon and the maintenance of its stability. This is what is meant by mitigation in the context of soil carbon. Figure 1 provides a simple illustration of the sequestration process.

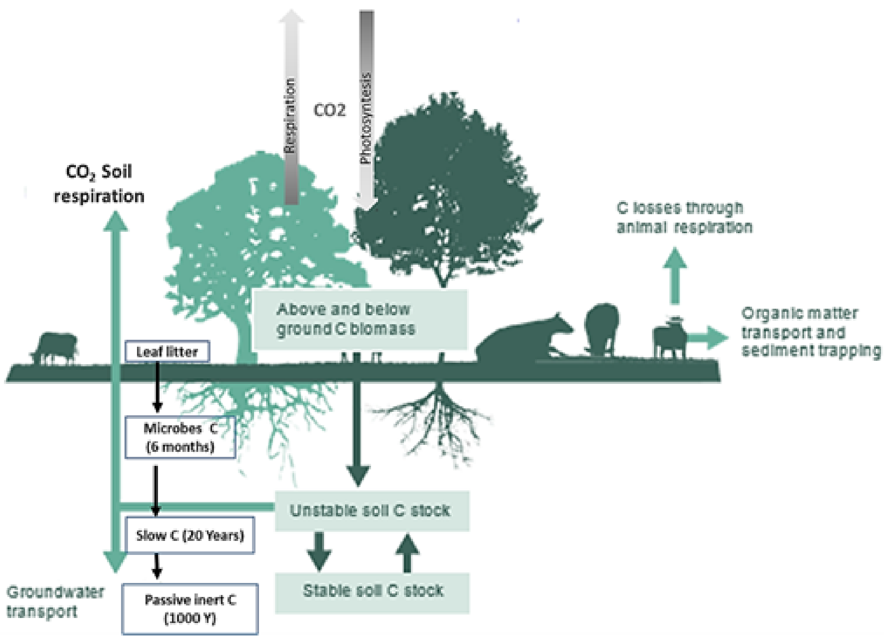

Figure 1. *Diagram of key carbon cycling dynamics in grazing ecosystems (source Garnett and al., 2017).*

In grazing ecosystems, the mechanisms driving the exchange of GHG between soil and water and the atmosphere are complex and knowledge of these ecosystems is lacking (Valentini et al. 2014), especially in tropical environments (IPCC 2013). Under arid to semi-arid conditions, soil moisture is one of the main factor controlling emissions of CO_2 (Kuzyakov and Gavrichkova 2010; Yemadje et al. 2016) and N2O from the soil (Ussiri and Lal 2013), while CH4 emissions occur only in hydromorphic conditions (Serrano-Silva et al.

2014). In pastoral ecosystems, large amounts of manure are produced and deposited, thereby directly or indirectly affecting GHG emissions via modifications of the chemical and physical properties of the soil (Thangarajan et al. 2013). Various processes are involved including microbial processes: (priming, methanogenesis, nitrification/denitrification) and modification of the physical characteristics of the soil (texture and moisture).

Livestock, as a vector of organic matter, also plays an important role in the spatial redistribution of nutrients and carbon. This is particularly true in West African agro-pastoral ecosystems (Manlay et al.2004a; Manlay et al. 2004b; Schlecht et al. 2004) and, due to the high mobility of herds and the importance of ruminants in the functioning of the ecosystem, a similar situation can be envisaged for pastoral ecosystems elsewhere. The resulting heterogeneous distribution of animal excreta in the landscape may affect the heterogeneity of soil properties and spatial variations in available nutrients as well as the distribution of plant roots. These factors significantly affect CO_2, N2O via microbiological processes (Smith et al. 2003).

How are carbon stocks and carbon sequestration rates in soils measured?

To assess the effect of a management practice on soil carbon, the classic approach consists of measuring the soil's organic carbon composition. One way is to use an auger (a type of drill) to take soil samples down to different depths. The soil is then analysed in a laboratory to obtain the C concentration. A more recent (non-destructive, more rapid, reproducible and low-cost) method consists of using near-infrared reflectance spectroscopy in soil analysis. The carbon stock is then calculated by evaluating the concentration of carbon (%) with the depth of the measurement by the soil's bulk density (g/m3). By repeating soil sampling over a range of years the change (loss or gain) in carbon stocks can be estimated. Typically, the top 30 cm of soils is considered as the soil compartment that contains the largest concentration of carbon. Nevertheless, while greater depths contain lower concentrations, they may store a great deal in absolute terms. Far less research has been conducted into these lower depths as measurements are harder to take. Flux measurements by eddy covariance are another way of estimating changes in soil carbon stocks. Eddy covariance is a powerful tool for measuring total ecosystem fluxes of carbon because it is able to detect changes in the net ecosystem exchange (NEE) of carbon at fine temporal resolution, and enables estimates to be made of whether given ecosystems or land management practices result in net sinks or sources of carbon.

These methods are hampered by limitations and uncertainties, in particular concerning our ability to measure soil carbon on a large scale. First, to get an accurate picture of current stocks and future changes, it is necessary to sample widely because of the high spatial heterogeneity of soils. Then, the temporal dynamics must be considered. The soil organic carbon content changes slowly and only marginally from year to year, so change needs to be measured over a long time-frame (more than 10 years). The rate of soil C accumulation can be determined by measuring soil C stocks over time at the same location (diachronic approach) or along a chronosequence that substitutes spatial history differences for time (synchronic approach where samples are taken at the same time from field plots under different land-use or management systems). Chronosequence studies are easier to set up but are often criticized for being "space-for-time" analyses which do not have the same starting point (e.g. soil texture) of measured sites (Stahl and al., 2017).

Any change in carbon is, moreover, being measured against huge background stocks. The 'noise' from the uncertainties in actually measuring the baseline stock can make it hard to measure the relatively small changes (Garnett and al., 2017).
An alternative to measurement methods is to use models. A large number of general computer models are currently being used to predict carbon sequestration in agricultural systems. These models fail to adequately replicate the impacts of different grassland management practices on carbon storage and GHG emissions compared to measurements on plots. Consideration of the mechanisms and processes involved in carbon stabilization and destabilization, particularly in relation to the impact of nitrogen fertilization on soil carbon stabilization, is still rather incomplete in large-scale models. There is therefore a need to advance these models, which for the most part fail to replicate the interactions between primary production and residence time of carbon in soils; both of these processes control the amount of carbon stored in soils.

THE CARBON SEQUESTRATION POTENTIAL OF GRASSLAND AND RANGELAND

What are the issues around grazing areas?

The total stock of SOC on earth (to a depth of 1 metre) is 1,500 GtC – twice the amount of carbon found in terrestrial vegetation, and three times the amount found in the atmosphere, making it a very significant global carbon pool. Peatlands store the most soil carbon per hectare by far, followed by boreal forests and then temperate and tropical grasslands. But because of their larger land area in absolute terms, boreal forests are the largest soil carbon stores, followed by temperate and tropical savannas – the latter hold about a third of total global soil carbon stocks. . Of course, there is also considerable carbon in above-ground vegetation

Ruminants are a major source of GHG emissions, particularly CH4 and N2O, but any soil carbon sequestration arising is small, uncertain, time-limited, reversible and difficult to verify. However, ruminants in well-managed grazing systems can sequester Ruminants are a major source of GHG emissions, particularly CH4 and N2O, but any soil carbon sequestration arising is small, uncertain, time-limited, reversible and difficult to verify. However, ruminants in well-managed grazing systems can sequester carbon in grasslands, so that this sequestration partially or entirely compensates for the CH4 generated by these systems. The landscapes of razing systems can balance the GHG emission by their low level of consumption g of non ‑ renewable energy and positive contribution to carbon sequestration. Grasslands which account for 30% of the land surface (3,5 billions of ha), store 30% of C soil stock (in the soil organic matter), or nearly 4% of anthropogenic GHG emissions (Lal, 2004). However, the carbon sequestration potential would range from 0 to 4 t C/ha/year depending on the ecological zone, soil characteristics, climatic conditions and agricultural practices (Soussana et al. 2010).

In pastoral ecosystems, the mechanisms driving the exchange of GHG between soil and water and the atmosphere are complex, and knowledge of these ecosystems is lacking (Valentini et al. 2014), especially in tropical environments (IPCC 2013). Garnett and al. (2017) point out the fact that the range in estimates is large. This reflects the uncertainties inherent in the estimation methods, and the differences in management practices, the geographical and agro-ecological context of the studies and data acquisition methods. For example, little information is available about possible long-term carbon sequestration in pastures or their capacity to store C in intermediate (20–50 cm) to deep soil (50–100 cm) layers (Stahl and al., 2017). The sequestration potential can vary from 0 to 150 kg C / ha / year in arid regions and from 100 kg to 1 t C / ha / year on wet and cold regions (VIgne et al., 2016).
A paper by Budiman and al. (2017) surveyed the soil organic carbon (SOC) stock estimates and sequestration potentials from 20 regions in the world, including grassland areas, but most studies on SOC sequestration only consider topsoil (up to 0.3 m depth). In a review. Chang and al. (2004) estimate that the carbon balance of European grassland (including in particular Ghg emissions) is estimated to be a net sink of 150 ± 70 Kg C m-2 yr-1 during 1961-2010, equivalent to a 50-year continental cumulative soil-carbon sequestration of 1 billion ± 0.4 t C. Valentini et al. (2014) estimate the net long-term carbon balance of African ecosystems based on observations (including losses from fire disturbance) gives a sink of the order of 200 millions C /year, albeit with a large uncertainty around this number. Some authors point out the fact that that simply having a grassland does not result is a carbon sink, and it is untenable that grasslands act as a perpetual carbon sink. (Smith , 2014). The author conclude that “high carbon stocks (total storage of carbon in grasslands, mainly in the soils), does not equate to large carbon sinks (the net annual removals of carbon from the atmosphere). On existing grassland, only through improving the grassland can soil C be sequestered, so where grassland management is poor, policy should seek to improve it. Secondly, since there is much more carbon to be lost from grasslands than can be gained, protecting large grassland carbon stocks should be a policy priority.”There as thus good grounds to take into account the potential capacity of pastures to sequester carbon in terms of mitigation, but it is equally essential to consider the risks and limits of this process (see § 3).

Case study: soil carbon stocks after conversion of Amazonian tropical forest to grazed pasture

The livestock farming development trend in the Amazon region clearly illustrates the new challenges of livestock production facing climate change. Livestock development in the Amazonian basin has fueled a lively international debate in recent decades. According to the FAO, approximately 80% of deforested areas were converted into pastures resulting in rapid carbon (C) emissions (~ 733 t CO_2eq. ha-1) (Blanfort et al., 2014). Efforts to curb deforestation should therefore continue to be a priority to preserve C stocks and forest biodiversity. In addition, this also needs to be accompanied by sustainable management of areas that were converted into pastures, including strategies for greenhouse gas (GHG) mitigation. However, little is known about the long-term capacity of tropical pastures to sequester C in different soil layers after deforestation. Deep soil layers are generally not taken into consideration or are underestimated when C storage is calculated.

In French Amazonia, research is being conducted to understand the long-term dynamics of C in deep soil of permanent tropical pastures established (with the grass Brachiaria humidicola) after deforestation from 1970 in French Guiana). A unique combination of a large chronosequence study (figure 2) and eddy covariance measurements (flux tower, figure 3) was set up. We compared this approach with eddy covariance flux measurements on two pastures and one native forest (Stahl et al., 2017). The results showed that pastures stored at least 1.27 ± 0.37 tC ha-1 yr-1 while the nearby native forest stored 3.23 ± 0.65 tC ha-1 yr-1. (figure 1).

The results suggest that in French Amazonia old permanent tropical pastures (≥ 24- year-olds) can restore a part of the C storage observed in native forest with appropriate practices (no fire and no overgrazing, but a mixture of grasses and legumes and a grazing rotation plan. It allows farmers to maintain these pastures in the long- term without the loss of soil fertility often observed in cultivated soils (McGrath et al., 2001). Conservation of soil fertility should help limit the conversion of new fertile areas and consequently, deforestation.

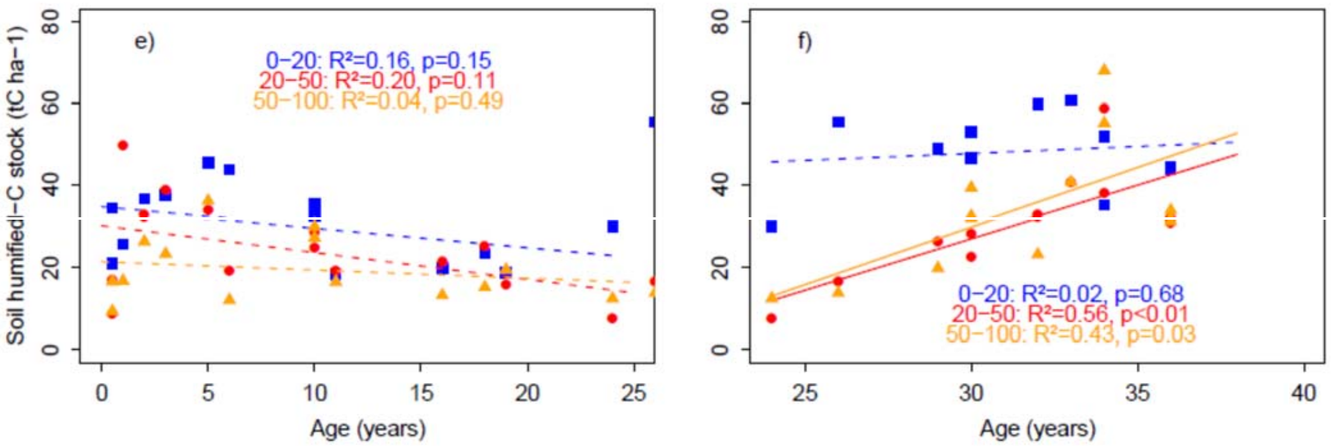

Figure 2 (Stahl and al., 2017). The inventory of soil C and N stocks at a depth of 1 m was conducted in a study of pasture chronosequence including 24 from six months to 36 years and four native forest sites. The figure show the carbon stock changes along the chronoséquence in different soil layers. This carbon is mainly sequestered in the humus of deep soil layers (20-100 cm), whereas no C storage was observed in the top soil (0-20 cm layer). Soil humified C stock in the three soil layers (0–20 cm: blue squares; 20–50 cm: red circles; 50–100 cm: orange triangles) under pastures ≤24 years old and (f) pastures ≥24 years old. Dashed lines mean no significant relationship between soil C stocks and the age of the pasture. Solid lines mean a significant linear relationship was found between soil C stocks and the age of the pasture.

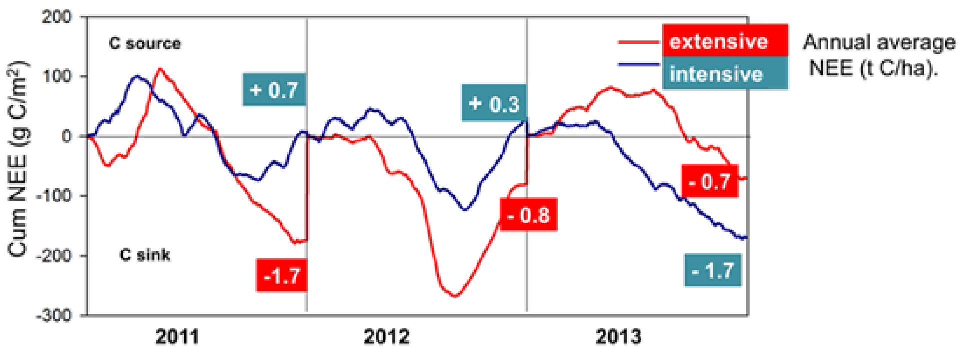

Figure 3. *Eddy covariance flux measurements was realized on 2 pastures show intra-annual variations of net C storage (NEE Net Ecosystem) as an effect of soil water conditions modulated by the management. Extensive management allows a better net C storage for dry years (2012), while during the wet years (2013) intensive grazing seems to be an advantage. Negative values indicate storage of C by ecosystems and positive value indicates release of C.*

CASE STUDY: GREENHOUSE GAS BALANCE OF A SAHELIAN RANGELAND ECOSYSTEM IN SEMI-ARID WEST AFRICA

In a very different context, the pastoral livestock farming in the Sahel is often accused of harming the environment and contribute to global warming. However a more systemic approach of a pastoral territory indicates much less harmful interactions between animals and their environment (Hassouma et al., 2017). An original recent study integrate the various components of the ecosystem (animals, soil, plants) and consider all components of the GHG balance at the landscape level. Results show that the annual net GHG balance of the ecosystem was -0.01±0.03 tC-eq/ha/year at landscape scale (cf Hassouma et al., 2017 in the chapter "Case studies" of this document).

What management practices to sequester carbon ?

At COP21, France set an international research program, the 4 per mille Soils for Food Security and Climate' of the Lima-Paris Action Agenda. The 4 per mille or 4 per 1000 aspires to increase global soil organic matter stocks by 0.4 percent per year as a compensation for the global emission of greenhouse gases by anthropogenic sources. Since 2015 it has been backed by almost 150 signatories (countries, regions, international agencies, private sectors and NGOs). Stakeholders committed in a voluntary action plan to implementing farming practices that maintain or enhance soil carbon stocks in agricultural soils and to preserve carbon-rich soils. (SOC) sequestration is seen as a possible solution to mitigate climate change, to take atmospheric CO2and convert it into soil carbon which is long-

lived. As soil stores two to three times more carbon than the atmosphere, a relatively small increase in the stocks could play a significant role in mitigating GHG emissions. The annual greenhouse gas emissions from fossil carbon are estimated at 8.9 gigatonnes C (8.9 × 1015 g), and a global estimate of soil C stocks to 2 m of soil depth of 2400 Gt (2400 × 1015 g), while most studies on SOC sequestration only consider topsoil (up to 0.3 m depth), as it is considered to be most affected by management techniques. Taking the ratio of global anthropogenic C emissions and the total SOC stock (8.9/2400), results in the value of or 4‰. Increasing SOC has been proposed to mitigate climate change with the additional benefit of improving soil structure and conditions (Budiman and al., 2017). As grasslands are among the largest ecosystems in the world, between (20-47% of the land area), grazing systems can be considered as a major ecosystem concerned by this initiative. Budiman et al. estimate that on 149 million km2 of the land area of the world, there are on average 161 tonnes of SOC per hectare. So 4 per mille thus equates to an average sequestration rate to offset emissions at 0.6 tonnes of C per hectare per year. This 4 per mille blanket value cannot be applied everywhere as soil varies widely in terms of C storage, which includes desert, peatlands, mountains. Nevertheless, studies across the globe have measured SOC sequestration rates and they suggest that an annual rate of 0.2 to 0.5 t C per hectare is possible, after the adoption of best management practices such as reduced tillage in combination with legume cover crops.

It is not possible within the framework of this synthetic paper to develop in detail the grazing management options favorable to the storage of carbon. However. It seems important to point out just some basic principles. Garnett and al., 2017) underline the point that "Livestock add neither new carbon nor nitrogen into the system. They merely contribute to their accumulation in some compartments (reservoirs) in soils, or in plant and animal biomass". As plants naturally take up carbon from the atmosphere, stimulating the rate of plant growth by using fertilisers, or by co-planting nitrogen- fixing legumes is a first approach to promote sequestration. But not all organic matter that enters the soil is converted into long term, stable soil carbon, since much of it is labile and leaves the system within a period of weeks, months or years . Additional, approach is to introduce deep rooting grasses such as Brachiaria spp. into the pasture (cf § 2.2) , the idea being that the carbon in the dead roots is stored deep underground in .

An other way to contribute to sequestering carbon on grazing lands is to manage the livestock through good grazing management. That means to manage the intensity of grazing by adjusting the stocking rate and the timing of grazing. Light to moderate intensity grazing is more likely to maintain soil carbon stocks and has greater potential to foster sequestration (on lands where this is possible) than continuously heavy grazing, which is usually damaging and reduces soil carbon.

CONCLUSIONS

The interactions between grazing farming activities and climate change, especially in the less developed regions, are complex. On the one hand, the entire livestock sector is a major contributor to the phenomenon in progress, mainly through its greenhouse gases emissions; it is subject on the other hand to climate change constraints to which it must adapt. Breeding has real ability to adapt while also offering significant and multiple mitigation potential. The necessary and obvious contribution to food security of large populations and the response to future demand for animal products necessitate the reconsideration of animals as contributors in designing climate-smart farming systems.

This reconsideration of pasture systems must of course be based on the experience of dairy/stock farmers, ranchers, pastoralists who adapt to climate variations is the basis of their activity. However, the major climatic disturbances already taking place and projected go beyond the climatic variability inherent in agricultural systems. It requires structured discussions between producers, livestock and crop farmers, private companies in the various commodity chains, policy makers and civil society. Research and development institutions are essential in this dynamic process. They must explain the issues and propose technical and institutional solutions that apply to the entire production chain and territory. Research is also involved and in "the North", scientific works now address these issues, but many uncertainties remain. In tropical areas, few references are available and significant work remains to be done to establish the baselines and strategies to support sustainable grazing activity in these regions where global sequestration potential is high, facing the surfaces concerned. Beyond local and regional issues, research can contribute to these questions about the role and challenges of grazed ecosystems in climate change and land use change while maintain/increase the productivity capacities of livestock sector. Livestock certainly remains a major GHG contributor, but it has been proven that the sector can significantly reduce emissions including carbon storage. Livestock could reduce its greenhouse gas emissions by 30% via greater use of better agricultural practices and existing technologies, while maintaining the objectives of doubling production in the South in particular in connection with the increasing demand.

In the context of climate change mitigation, the carbon issue was first addressed by the forest domain identified as the most carbon-storing sector in aboveground biomass. Then, when the storage of carbon in the soil compartment has become a significant additional option, crops agronomy sector has naturally integrated the theme because of a significant history of soil organic matter (SOM is composed of near 50% of C). Livestock's place on climate issues is still largely regarded in terms of contribution to GHG emissions, in particular methane. It is now crucial to highlight the role of grazing land in terms of mitigation. But for the message to be clear, and to be able to generate appropriate actions, ambiguities and uncertainties still need to be assessed. Soil carbon sequestration in grazing systems is not an evidence, but their capacity to contribute to the process is real, and more research is needed (among others) to clarify the conditions of implementation.

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